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Implementation and Rejection of Industrial Steam System Energy Efficiency Measures

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Abstract

Steam systems consume approximately one third of energy applied at U.S. industrial facilities. To reduce energy consumption, steam system energy assessments have been conducted on a wide range of industry types over the course of five years through the Energy Savings Assessment (ESA) program administered by the U.S. Department of Energy (U.S. DOE). ESA energy assessments result in energy efficiency measure recommendations that are given potential energy and energy cost savings and potential implementation cost values. Saving and cost metrics that measure the impact recommended measures will have at facilities, described as percentages of facility baseline energy and energy cost, are developed from ESA data and used in analyses. Developed savings and cost metrics are examined along with implementation and rejection rates of recommended steam system energy efficiency measures. Based on analyses, implementation of steam system energy efficiency measures is driven primarily by cost metrics: payback period and measure implementation cost as a percentage of facility baseline energy cost (implementation cost percentage). Stated reasons for rejecting recommended measures are primarily based upon economic concerns. Additionally, implementation rates of measures are not only functions of savings and cost metrics, but time as well.

[keywords: steam system efficiency, industrial energy efficiency, industrial energy efficiency barriers]

Introduction

Industrial sector energy consumption (defined as the quantity of energy applied to an entity) (ISO, 2011) accounted for 32% of the 105.5 EJ of energy applied within in the United States in 2008 and cost the industrial sector US$247.19 billion (DOE, 2011). To increase industrial energy productivity and facilitate competitiveness, the U.S. government promotes energy savings measures. While the government can encourage facilities to adopt energy efficiency measures, ultimately individual facilities decide whether or not to implement these measures.

Industrial energy systems can be disaggregated into five major system types: steam, process heat, fans, pumps, and compressors. Steam systems account for one third of all industrial energy consumption, and will be the focus of this study (DOE, 2002a, 2006). Industrial steam is used to heat raw materials and treat semi-finished products. It is also a power source for equipment, as well as for building heat and electricity generation (DOE, 2002a, 2012c).

Industrial sectors that use fossil fuels as an energy source typically devote significant proportions of these fuels to steam production. Such sectors include: pulp and paper (81%), food processing (57%), chemicals (42%), petroleum refining (23%), and primary metals (10%) (Einstein et al., 2001). Due to this reliance on steam, improving steam system energy efficiency can greatly reduce industrial energy consumption and cost. The U.S. DOE has estimated that energy and associated expenditure savings of 10-15% can found throughout industrial steam systems (DOE, 2012c).

The U.S. DOE offers a large number of publications, trainings, and tools aimed at reducing industrial energy consumption. Additionally, the U.S. DOE offers facility energy assessments through their Industrial Assessment Centers (IAC) and the Energy Savings Assessment (ESA) program. Small and medium facilities (fewer than 500 employees and gross annual sales below US$100 million) can participate in a one to three day IAC assessment while the largest, most energy-intensive industrial plants in the U.S. can receive a three-day assessment as part of the ESA program. IAC assessments are conducted for all facility system types while ESA assessments target one of the five major system types: compressors, fans, process heating, pumps, and steam. Both assessment programs establish a baseline of energy consumption and energy cost in addition to recommending energy saving measures. Follow up assessments record energy and cost savings reported due to implementation of recommended measures.

The U.S. DOE has been collecting ESA assessment data since October of 2007. The ESA database contains assessed facility baseline energy consumption and cost along with recommended steam system energy efficiency measures. Potential annual energy and energy cost savings values as well as an implementation cost value are provided for recommended energy efficiency measures. Three follow up assessments conducted six, 12, and 24 months following the initial assessment are made. During follow-up assessments, recommended energy efficiency measure implementation status is recorded as either implemented, in progress, or rejected. Additional measures are not recommended. For implemented measures, reported energy and energy cost savings as well as implementation cost are recorded. In the case of measure rejection, a reason for rejection is selected for a pre-determined pick list.

Facilities that participate in the ESA program are not required to publicly report and the database used for this paper has been expunged of all facility identification. However, a number of ESA assessment case studies are available that do identify facility information (DOE, 2012b).

This study examines five years of available ESA data to determine factors that affect the implementation or rejection of steam system energy efficiency measures recommended to U.S. industrial facilities, the accuracy of predicted energy and energy cost savings, as well as implementation cost and payback are compared to reported values. Additionally, barriers preventing implementation are examined in the form of measure rejection reasons. These reasons are assessed in a manner that parallels previous studies that have identified energy efficiency deployment barriers (Brown, 2001; DeCanio, 1993; Palm and Thollander, 2010; Rohdin and Thollander, 2006; Schleich and Gruber, 2008; Sorrell et al., 2000; Sovacool, 2009; Thollander et al., 2007; Trianni and Cagno, 2012; Umstattd, 2009; Weber, 1997). Finally, the rate of implementation is studied as a function of savings and cost metrics as well as time. By understanding factors that drive energy efficiency measure implementation, governments and policy makers can better target steam system efficiency measure recommendations to industry.

Methodology

This study of industrial steam system energy efficiency measure implementation and rejection was conducted by analyzing steam system energy assessments in the ESA database. The ESA database includes facility baseline energy consumption and energy cost, recommended energy efficiency measures, measure savings and cost values, and implementation status of recommended measures recorded six, 12 and 24 months following an initial assessment. If a measure has been rejected, a reason for rejection is selected from a pick list and recorded.

The ESA database includes 1165 energy assessments made at 928 unique facilities for all system types: compressors, fans, process heating, pumps, and steam. A number of facilities participated in multiple assessments; most of which focused on different system types, though a few facilities requested multiple assessments for the same system type. Of all assessments, 42% focused on steam systems, and are the subject of this paper. Steam systems account for 53% of total database facility baseline energy consumption and 51% of total facility energy cost. The second largest energy system, process heating, accounts for 29% of assessments, 25% of total facility energy consumption, and 27% of total facility energy cost.

For this analysis, incomplete and non-steam system assessments and facilities were removed from the database, resulting in 105 assessments conducted at 104 facilities. Incomplete data included assessments with no baseline data, or assessments that did not have complete six, 12, and 24-month reassessment entries. One general manufacturing facility received two distinct steam system assessments. These two assessments are included independently and are not aggregated. The assessments include 606 energy efficiency measures recommendations made up of 98 unique steam system energy efficiency measures.

Figure 1 shows facility baseline energy and energy cost data for all facilities in the ESA database. Each facility is represented by the outline of a black diamond. Black diamonds filled in with red indicate facilities that received a steam system assessment, including those assessments deemed to be incomplete. Lastly, green circles indicate facilities that took part in a steam system and are included in this analysis. Figure 1 shows that the facilities included in this paper matches well with the overall distribution of facilities in the ESA database. Figure 1 highlights the linear relationship between facility energy consumption and energy cost.

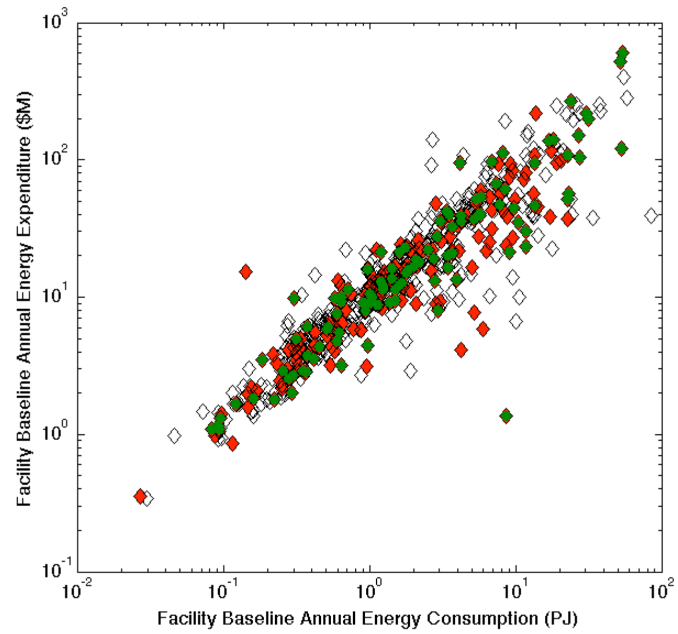

Figure 1: ESA Facility Baseline Energy Consumption and Energy Cost

This analysis of steam system assessments is conducted with aggregated data. However, as reference information, facility energy consumption, energy cost, and industry type are disaggregated. Assessments are disaggregated by annual facility energy consumption into four bins: less than 0.2 PJ; 0.2 to 0.4 PJ; 0.4 to 4.2 PJ; and greater than 4.2 PJ. The columns of Table 1 list the number of facilities that fall into each of these bins.

Additional disaggregation is made based upon self-identified industrial sectors. The five most commonly assessed sectors are: chemical; forest products; food processing; general manufacturing; and automotive. These sectors constitute 86% of assessments and are known to use large quantities of energy to produce steam (DOE, 2002b). Industrial sectors are not individually analyzed in this paper but are listed in Table 1 as reference.

Table 1: Number of Assessments included in Analysis. Aggregated and Disaggregated by Annual Facility Energy Consumption and Industrial Sector.

	All Assessments	Less Than 0.2 PJ	0.2 – 0.4 PJ	0.4 – 4.2 PJ	Greater Than 4.2 PJ
Aggregated	105	7	11	52	35
Chemical	32	0	3	10	19
Forest Products	21	0	0	12	9
Food Processing	21	7	5	8	1
General Manufacturing	10	0	2	6	2
Automotive	6	0	1	5	0

Table 2 lists aggregated and disaggregated assessed facility energy consumption and energy cost data. Data are summed and averaged in aggregate and per disaggregated bin. In total, assessed facilities annually consumed 721.9 PJ of energy at a cost of US$5.2 billion. The chemical sector is the largest consumer of energy in total and per assessment. The five disaggregated sectors do not share common energy consumption or energy cost values per assessed facility. Facilities that consume 4.2 PJ or more of energy account for the majority of total energy consumed and energy cost. The number of facilities that consume greater than 4.2 PJ of energy is larger than any other energy consumption bin and the energy consumed per facility in this bin is considerably higher than those in other bins.

Table 2: Total and Averaged Assessed Facility Energy Consumption and Energy Cost in Aggregate and Disaggregated.

	All Assessments		Annual Facility Energy Consumption		Annual Facility Energy Cost	
			Summation	Average	Summation	Average
			(PJ)	(PJ)	(US$M)	(US$M)
	105	Aggregated	721.9	6.87	$5,191.2	$49.9
Top Five Industrial Sectors	32	Chemical	399.4	12.48	$3,134.0	$97.9
	21	Forest Products	112.1	5.34	$724.8	$34.5
	21	Food Processing	21.1	1.00	$123.9	$5.9
	10	General Manufacturing	29.0	2.90	$183.4	$18.3
	6	Automotive	7.0	1.67	$63.8	$10.6
Facility Annual Energy Consumption	7	< 0.2 PJ	0.8	0.11	$11.6	$1.7
	11	0.2 – 0.4 PJ	3.5	0.32	$43.1	$3.9
	52	0.4 – 4.2 PJ	89.9	1.73	$844.3	$16.2
	35	> 4.2 PJ	627.6	17.93	$4,292.1	$122.6

Energy efficiency measure potential and reported savings and cost values are provided in the ESA database. These values are functions of facility steam system energy consumption and energy cost, making direct comparison of the savings and cost values from different assessments unreliable. Use of energy consumption and energy cost as proxies for facility steam system energy and energy cost allows for normalization of these savings and cost values, thus making direct comparison of measure savings and cost metrics from different assessments possible. Four metrics not native to the ESA database were calculated and used in this analysis: energy savings percentage, energy cost savings percentage, implementation cost percentage, and payback period. Potential and reported versions of each metric were calculated. The four metrics are detailed:

- Energy savings percentage = 100 * measure potential annual energy savings / baseline facility annual energy consumption
- Energy cost savings percentage = 100 * measure potential annual energy cost savings / baseline facility annual energy cost
- Implementation cost percentage = 100 * potential measure implementation cost / baseline facility annual energy cost
- Payback period (months)= (measure implementation cost / annual energy cost savings) x 12 months

Calculated savings and cost percentage values represent the impact a recommended measure will have at a facility. Greater energy savings percentage values indicate that implementation of an energy efficiency measures will result in a larger fraction of facility energy consumption being reduced as compared to a measure with lower energy savings percentage. Similarly, a large energy cost savings percentage value indicates a measure will reduce a large fraction of facility energy cost as compared to a measure with a lower energy cost savings percentage. For these two savings metrics, a higher value equates to greater positive impact with regards to facility energy consumption and energy cost.

A large implementation cost percentage value indicates that implementing a recommended energy efficiency measure will require an investment that represents a large fraction of the total annual facility energy expenditure. Payback period specifies the length of time before the cost of implementing an energy efficiency measure is recuperated through energy cost savings.

Results

The examination of ESA steam system assessments focuses on the implementation and rejection of recommended energy efficiency measures. Analyses of: measure recommendations, implementations and rejections, reported barriers to implementation, recommended measure savings and cost accuracy, and time dependency of measure implementation are included.

Recommended Energy Efficiency Measures

During initial ESA assessments, energy efficiency measures are identified and recommended to assessed facilities. Measures are selected from a pre-defined pick list common to the IAC and ESA programs. Recommended measures are ascribed potential energy and energy cost saving values and potential implementation costs. Measures are recommended to facilities based upon the observations and expertise of the assessor, not preset formulas related to facility energy consumption, energy cost, or industry type.

Of the 105 analyzed assessments, 84% received between two and eight recommendations. A small fraction of facilities were recommended more than 8 measures, to a maximum of 15 measures recommended to one facility. 24% of all assessments included 5 recommended measures. In some instances measures were recommended multiple times during a single assessment. This typically occurred when a facility employed multiple steam systems. The number of recommendations made during an assessment and the associated potential energy and energy cost savings do not relate to facility energy consumption, energy cost, or industry type.

All 606 recommended energy efficiency measures are illustrated in Figure 2. The figure shows potential energy cost savings percentage against potential energy savings percentage. Marker color denotes potential payback period and marker size represents potential implementation cost percentage. A black reference marker is provided with a potential implementation cost percentage of 1.0%. A small percentage of recommended measures reported negative potential energy savings values. These measures are not often implemented and more typically have positive energy cost savings percentages. Such measures include those that involve installing combined heat and power systems, larger boilers, or steam driven equipment as replacement for electric powered equipment. Recommended measures with positive energy savings have typical potential energy savings that range from 0 and 20% and potential energy cost savings that would save between 0 and 15% of facility energy cost each year. A linear relationship between energy and energy cost savings percentages exists. Cost metrics (payback period and potential implementation cost percentage) are not functions of savings metrics (energy and energy cost savings percentage).

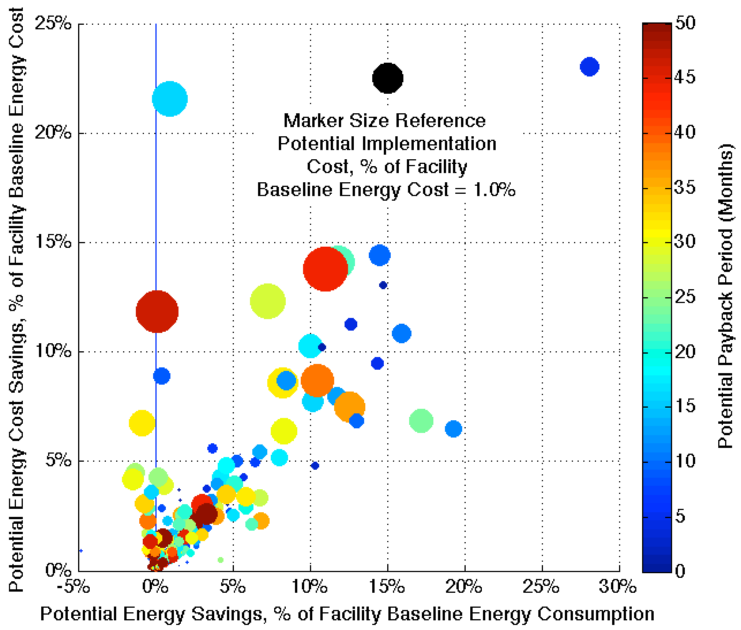

Figure 2: All Recommended Steam System Energy Efficiency Measures and Respective Savings and Cost Metrics.

In addition to analysis of recommended measures in aggregate, select energy efficiency measures are disaggregated and analyzed. To reduce statistical skew, only measures recommended 10 or more times are disaggregated. Of the 98 unique measures, 16 measures meet this requirement. These 16 measures account for 64% of all recommendations made, 75% of total recommended potential energy savings, 51% of total recommended potential cost savings, and 42% of total recommended potential implementation cost.

Listed in Table 3, the 16 measures are assigned measure numbers in order of descending implementation rate 24-months after initial assessment. Additionally, Table 3 lists the number of times a measure was recommended along with averaged energy efficiency metrics: potential energy savings, potential energy savings percentage, potential energy cost savings, potential energy cost savings percentage, potential implementation cost, potential implementation cost percentage, and potential payback. Table 3 provides an accessible connection between absolute savings and costs and associated percentage values. Average, maximum, and minimum measure metric values are included providing comparative ranges.

Energy efficiency measures listed in Table 3 are found in other U.S. DOE steam system efficiency reports and studies, including ESA assessment case studies and steam system tip sheets. Ten measures found in Table 3 are mentioned in these other documents (DOE, 2012c). Additionally, nine measures listed in Table 3 are mentioned as top steam system energy efficiency measures in a U.S. DOE steam system best practices handout (DOE, 2006). Industrial steam system energy efficiency measures listed in Table 3 are found in lists and reports generated by third parties including: IAC top 50 most recommended measures for all system types including steam (DOE, 2012a), IAC top 10 steam system potential energy cost savings list by ORNL (Wright et al., 2010), and a steam system energy efficiency study by LBNL (Einstein et al., 2001). Varying fonts identify measures listed in Table 3 that are found in third party lists and reports: underlined (IAC top 50), **bold** (**ORNL report**), and *italicized* (*LBNL report*).